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MARS SURFACE THERMAL ENVIRONMENT FOR VIKING LANDER DESIGN AND TEST

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ABSTRACT

Mars surface thermal environments have been developed for design and testing of the Viking lander, based on mission requirements and available Mars thermal data.

INTRODUCTION

The Viking program is intended to place two soft landers on the surface of Mars during 1976 for extended observations and transmittal of data to Earth. They must be able to survive many days of whatever environments may be encountered. It is well known that the Mars surface environment will vary greatly with season, latitude, and time of day. However, since the Viking landers will be the first weather stations on Mars, there are a great many unknowns.

The purpose of this work was to develop a rationale for defining the probable range of thermal environments, obtain the required Mars thermal data, and then define the specific combination of environments to be used in the design and testing of the Viking lander. The scope of this paper includes the derivation and results of the work of establishing these environments, but not the vehicle thermal design, testing, or performance.

The thermal environment parameters to be specified depend on the general design and mission objectives of the Viking lander. The Viking mission definition determines the ranges of landing sites and mission dates to be considered. The basic data for the surface, atmospheric, and astronomical parameters are taken primarily from the Mars Engineering Model prepared by the NASA Langley Research Center for the Viking program (Reference 2). Many of the parameters used in this study have been continually updated as better information became available.

ENVIRONMENTAL FACTORS

Factors Affecting Lander

The Viking lander is affected by many types and modes of heat transfer, including solar and infrared radiation, forced and free convection and gas conduction. The cyclic and mean daily thermal conditions and their variations with landing site and time of year are required to establish the design requirements. The environments for specific lander areas or external components are also affected by the specific vehicle configuration and orientation, and must be considered in the detailed lander design, especially for critical exposed components.

The pertinent solar radiation parameters are the solar irradiance, solar angle, daily solar radiation time, and solar radiation absorptivity of Mars and vehicle surfaces. The infrared radiation parameters are the Mars surface and effective sky temperatures and Mars and vehicle surface infrared emissivities. The terrain configuration could also affect both solar and infrared radiation by modifying the vehicle to soil view factors and reflections and introducing solar radiation shadowing. Forced convection depends on the wind speed, free convection on the acceleration of gravity, and both depend on the atmospheric temperature, pressure, and physical properties. The lander insulation performance and internal heat transfer are affected by the atmosphere conductivity and pressure.

Mission Specifications

The mission specifications affecting the environment are the ranges of landed mission dates and landing sites given in Reference 1. The solar radiation, the surface, atmosphere and sky temperatures, and the atmospheric pressure vary with these factors. The landed mission season or time of year on Mars and the landing site latitude are the most important parameters in determining the thermal environment.

The specified range of arrival dates at Mars is June 17 to August 13, the time in orbit is 10 to 50 days, and the landed mission time span is 90 days. Thus, the design landed mission is from June 27 to December 31, 1976. The actual end of mission may occur earlier because of loss of communication caused by occultation of Mars by the sun, but the design requirement extends through December.

The mission landing site latitude range was specified as 30 deg south latitude to 30 deg north latitude. Currently, further north landings are being considered, but none of these has more extreme conditions than the extreme hot and cold cases occurring for the original latitude limits. The range of elevations considered is from 3 km above to 9 km below the mean surface level. Potential landing sites are selected to have anticipated slopes not over 19 deg, and studies have shown that relatively moderate slopes have little effect on the environment. Therefore, for this study the terrain is assumed to be level.

Mars Thermal Data

The pertinent thermal data for Mars are taken primarily from the Mars Engineering Model (Reference 2) with some additional information obtained from other sources (References 3-8).

The required astronomical constants are the mean solar day of 24.66 hrs, the solar constant at one A.U. of 429 ± 1.5% Btu/hr-ft^2, and Mars surface gravity of 12.146 ft/sec^2. The Mars-Sun distance, solar irradiance at Mars, and aerocentric solar declination (angle between Mars equator and sub-solar latitude) vary with Earth date as shown in Figures 1 and 2. The daily solar radiation time span on Mars varies with Earth date and Mars latitude as shown in Figure 3.

The soil properties affecting the environment are the solar absorptivity, infrared emissivity and thermal inertia parameter (the square root of the product of soil density, thermal conductivity and specific heat). The presence of dust on the lander surfaces affects their optical properties. The pertinent atmospheric properties are the composition, pressure at the mean surface level and its variation with altitude, physical and thermal properties, transmissivity to solar radiation, and peak steady state wind speed. The effective sky temperatures are obtained from the other parameters for the various atmospheric models as described in References 7 and 8. Values for some of these surface and atmospheric parameters are given in Table 1. The ranges of most atmospheric parameters such as pressure, composition and thermal conductivity have decreased considerably in significance with each new set of model atmospheres.

The thermal inertia values used in this study are for particulate soils having about 50 percent voids, which are believed to cover much of Mars (Reference 2). Solid rock has a much higher value and would greatly attenuate the daily surface temperature fluctuations. The normal atmospheric transmissivity of nearly 100 percent is used. Martian clouds, especially the dust clouds observed by Mariner '71 have a radical effect on the environment. As in the case of heavy terrestial clouds, they would attenuate the surface and atmospheric temperature extremes and reduce the incoming solar and outgoing infrared radiation.

DESIGN CONDITION SELECTION

Mars Properties

The mean or most probable values for all parameters are used to obtain the nominal environments. The hot and cold design environments are obtained by using the heating or cooling design limits for these parameters. However, the limiting conditions to be used for certain parameters are not immediately obvious. Moderate variations in soil thermal inertia have very little effect on the mean surface temperature, but the daily peak surface temperature varies inversely with the thermal inertia to a significant degree.

Wind has a cooling effect in the cold case, since the external environment is always much cooler than the lander interior. In the hot case, the mean exterior environment is also

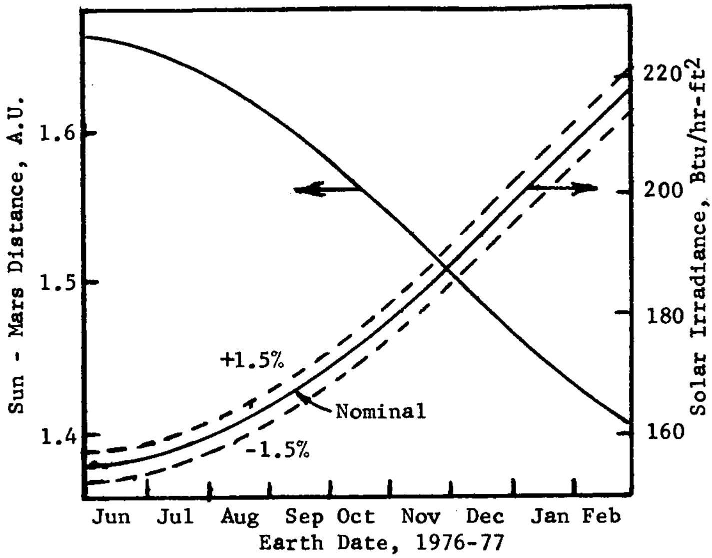

FIGURE 1 - SUN-MARS DISTANCE + SOLAR IRRADIANCE AT MARS

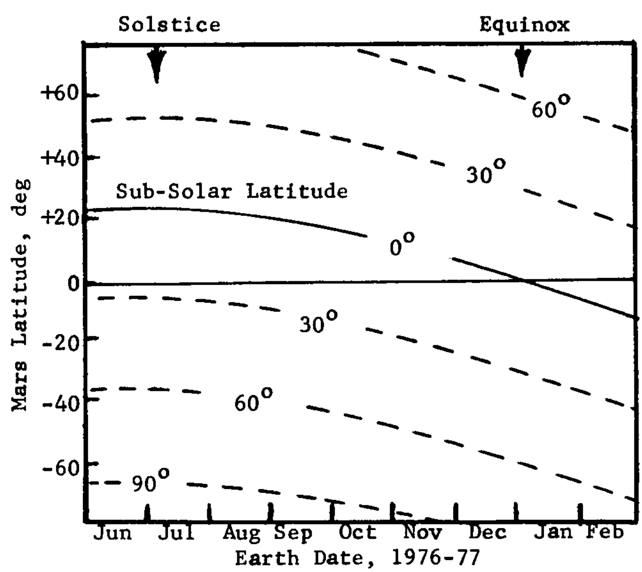

FIGURE 2 - NOON SOLAR ANGLE ON MARS

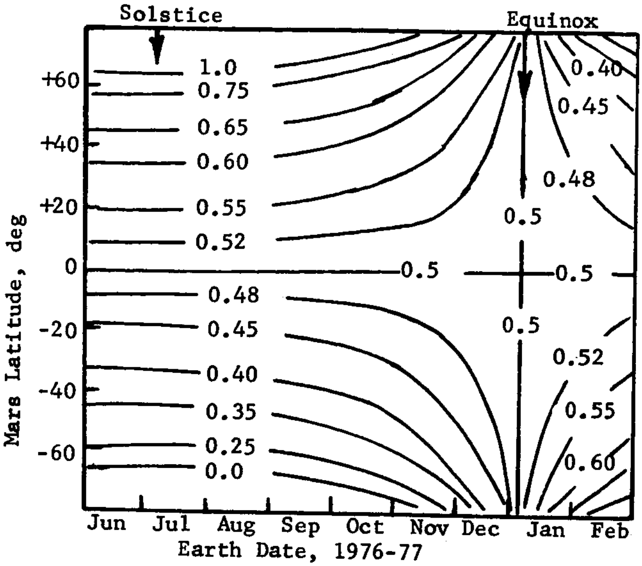

FIGURE 3 - SOLAR RADIATION FRACTION OF DAY ON MARS

TABLE 1 - MARS SURFACE PHYSICAL AND OPTICAL PROPERTIES

Surface Albedo Dependent	Light Area	Average	Dark Area
Surface Albedo (Reflectivity)	0.25	0.23	0.15
Surface Solar Absorptivity	0.75	0.77	0.85
Soil Thermal Inertia, Btu/^{o}F-ft^{2}-hr$^{\frac{1}{2}}$	0.55$\pm$0.12	0.59$\pm$0.12	0.74$\pm$0.12
Atmospheric Model Dependent	**Minimum P**	**Nominal P**	**Maximum P**
Pressure, Mean Surface Level, mb	4.0	5.3	8.0
Atmosphere Composition, wt % CO_2	100	100	82
wt % Ar	0	0	18
Thermal Conductivity at -46^{o}F Btu/hr-ft-^{o}F	0.0074	0.0074	0.0075
Effective Sky Temperature, as Function of Surface T, ^{o}F	-188.9 +0.664T	-177.3 +0.658T	-177.3 +0.658T
Independent Variables	**Minimum**	**Nominal**	**Maximum**
Surface Infrared Emissivity	0.89	0.93	0.96
Landing Site Elevation, km	-9	-3	+3
Wind Speed at Surface, ft/sec	0	65	130

colder than the lander interior, but wind tends to heat the lander during part of the day. However, a wind that starts and stops in a specific pattern every day is considered sufficiently unlikely to be excluded, and the no wind condition is assumed to be generally hotter. Since the wind is one of the least known and widest varying parameters which may have a major thermal effect, insensitivity to wind speed must be considered in vehicle design.

The values tending to produce the highest mean and/or peak Mars surface and atmospheric and vehicle surface temperatures and the least heat loss from the lander are used for the hot environments. The selected surface properties are dark soil for a high solar absorptivity, low emissivity, and low thermal inertia for a dark area. The atmosphere selected has the lowest thermal conductivity and pressure and the highest effective sky temperature. A plus tolerance on the solar constant, a zero wind speed, and a dust covered lander for high solar absorptivity are also assumed.

The values tending to produce the lowest mean and/or peak temperatures and the greatest heat loss from the lander are used for the cold environments. The selected surface properties are a light soil for a low solar absorptivity, high emissivity, and high thermal inertia for a light area. The atmosphere selected has the highest thermal conductivity and pressure and the lowest effective sky temperature. A minus tolerance on the solar constant, the maximum steady state wind speed, and a bare lander surface are also assumed.

Mars Temperatures

The daily surface temperature cycles for hot, nominal and cold environments were derived for Mars as functions of Earth date and Mars latitude. The atmospheric temperature at Mars surface is assumed equal to the surface temperature. This assumption is generally conservative as the atmospheric temperature normally fluctuates less than that of the surface. The computer model used to obtain these temperatures has several soil layers increasing in thickness with depth. The lowest layer has a nearly constant temperature close to the average surface temperature, which is consistent with actual subsoil conditions. The upper atmosphere temperature and pressure profile shapes are assumed constant throughout the day for a given atmospheric model. Thus, the effective sky temperature used for each case depends only on the average atmospheric temperature at the surface and the model atmosphere used. The parameter values used for the various cases are those described in the preceding section.

The mean daily temperatures for the nominal environments are presented in Figure 4 for the ranges of Earth dates and Mars latitudes of primary interest. This plot indicates the ranges and distributions of mean daily temperatures to be encountered during the mission. Several representative diurnal temperature cycles, including those for the hot and cold design cases, are shown in Figure 5. These curves indicate the extremely wide ranges of daily temperatures characteristic of these latitudes on Mars.

Mission Design Points

The selected design point for the cold case is on July 4, the time of Mars northern solstice and shortly after aphelion, and at a landing site 30 deg south latitude. This point corresponds to a low solar irradiance, minimum solar elevation angle and shortest daily solar radiation time for this mission. This time was picked rather than the earliest landing date, which could be colder, because the solstice time is fixed and not subject to changes in mission definition, and the environment at 30 degrees south varies little during late June and early July. It is also the goal date for the first Viking landing.

The hot design point is on December 31, the mission time nearest the equinox and approaching perihelion, and at a landing site one deg north latitude, the subsolar point at that time. These conditions correspond to the maximum solar irradiance for this mission, the maximum solar elevation angle, and the nominal daily solar radiation time. The highest temperature occurs at the sub-solar point when it is at the equator.

The nominal case is selected to be on October 2, the latest landing date and end of mission for the July 4 landing date, and at a landing site on the equator, the midpoint of the original landing site range. These conditions produce an environment very close to the median or most probable environment for the specified mission ranges as shown in Figure 4.

DESIGN ENVIRONMENTS

The conditions used for the hot extreme, cold extreme, and several intermediate environments are given in Table 2. The corresponding surface temperature diurnal cycles are given in Figure 5. The nominal case represents the most probable set of conditions and thus the most probable thermal environment anticipated for much of the mission. The cold design case represents the coldest environment to be met during any part of the mission, including the proposed landings near 45 deg north latitude. The hot design case represents the hottest environment to be encountered during any part of the mission.

The intermediate environments are useful in determining most probable conditions and margins, while the extreme hot and cold cases are used for vehicle design and test limits. The cold and hot cases have another major difference besides their wide difference in temperatures. The cold case is convection dominated because of the low temperatures, low solar flux and high wind speed, while the hot case is radiation dominated because of the high temperatures, high solar flux and low atmospheric free convection.

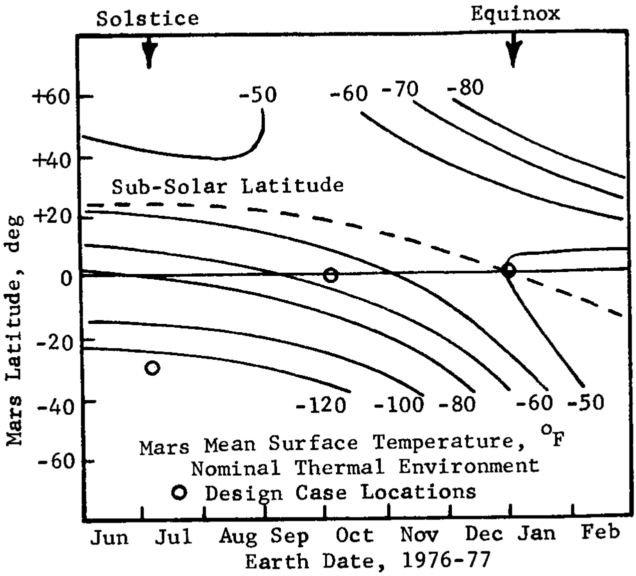

FIGURE 4 - MARS MEAN SURFACE TEMPERATURES

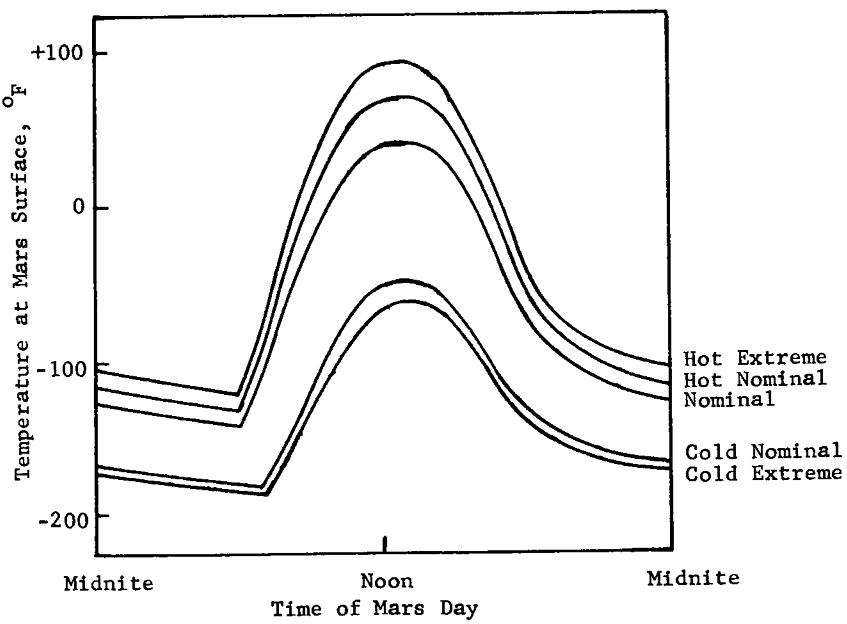

FIGURE 5 - MARS DIURNAL TEMPERATURE CYCLES

The available Mariner data, such as Reference 9, have been compared with these results and found to fall within the design limits. The Mariner measurements cover relatively wide areas, while the Viking design environments must consider local conditions. The Mariner data indicates that wind and blowing dust do exist on Mars, and that severe dust storms modify the environment by attenuating the radiation and temperature peaks at the surface. The design environments will be reviewed as more Mariner data become available.

TABLE 2 - MARS SURFACE MODEL ENVIRONMENTS

TIME/PLACE	Cold Case	Nominal Case	Hot Case
Event	North Solstice	Late Landing	Mission End
Earth Date, 1976	July 4	Oct. 2	Dec. 31
Solar Latitude, deg	+24.77	+18.45	+0.96
Solar Irradiance, nominal-$Btu/hr\text{-}ft^2$	156.3	170.9	198.3
Lander Latitude, deg	-30.0	0.0	+0.96
Irradiance Time, hr	10.21	12.33	12.33
Lander Altitude, km	-9	-3	+3

THERMAL CONDITIONS	Cold	Nominal	Nominal	Nominal	Hot
Solar Irradiance					
Tolerance, $Btu/hr\text{-}ft^2$	-2.3	0.0	0.0	0.0	+3.0
Surface Properties					
Solar Absorptivity	0.75	0.77	0.77	0.77	0.85
Infrared Emissivity	0.96	0.93	0.93	0.93	0.89
Thermal Inertia, $Btu/^{o}F\text{-}ft^2\text{-}hr^{1/2}$	0.67	0.59	0.59	0.59	0.62
Atmosphere Properties					
Pressure at Site, mb	20.2	6.8	6.8	6.8	2.85
Composition, wt % CO_2	82	100	100	100	100
wt % Ar	18	0	0	0	0
Conductivity at -46^{o}F $Btu/hr\text{-}ft\text{-}^{o}F$	0.0075	0.0074	0.0074	0.0074	0.0074
Wind Speed, ft/sec	130	65	65	65	0
Temperatures					
At Surface, ^{o}F Max	-60	-46	+42	+72	+95
Mean	-139	-132	-67	-50	-34
Min	-184	-180	-141	-131	-121
Sky (Effective), ^{o}F	-281	-264	-221	-210	-200

CONCLUSIONS

1. The most critical thermal environment parameters and the values to be used depend on the type of vehicle and mission objectives.
2. The thermal environments defined in Table 2 are conservative but reasonable for the thermal design and testing of the

Viking lander.

3. The most probable variations in parameter values from those used for the extreme design cases will produce less extreme environments.
4. These Mars thermal environments present very wide ranges of temperatures, solar radiation, wind and dust conditions which must be considered in the Viking lander thermal design.
5. These environments should be reviewed as more data become available to prevent unnecessary conservatism in the vehicle design and operation.

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